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<p>Experiments currently in progress are designed to quantify the information in the average firing rates of cochlear nucleus neurons. Single unit responses to best frequency tone bursts are recorded, and Receiver Operating Characteristic (ROC) curves are generated from empirical spike count distributions. In order to quantify the amount of information present for an increase in discharge rate, the area under the ROC curve, P(A), is computed. For a given difference in the means of two spike count distributions regular units (such as choppers) typically give larger P(A) values than do some irregular units (primary-like or transient chopper units). These results suggest that rate information may be enhanced in certain subsystems of the cochlear nucleus.</p>			
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INFORMATION PROCESSING OF COMPLEX SOUNDS IN THE ANTEROVENTRAL
COCHLEAR NUCLEUS (AFOSR-86-0326)

September 1986 to March 1988

Final Progress Report

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AFOSR-TR. 88-0850

Specific Aims of Previous Grant

1. We proposed to carry out single unit recording experiments in the cochlear nucleus to establish whether a rate-place representation of tones and tones in noise are preserved by the chopper units (stellate cells) of the AVCN. Single unit recordings from neurons in the cochlear nucleus were carried out. In order to obtain an objective measure of how much information is present in the average discharge rate, we applied techniques derived from Signal Detection Theory to empirical spike count distributions obtained from cochlear nucleus units (see Detailed Progress Report).

2. We proposed to investigate the encoding of rippled noise (cosine noise) in the auditory nerve and AVCN. The overall objective was to describe the temporal and rate information present in the auditory nerve, and then investigate how the primary-like units (bushy cells) and chopper units (stellate cells) preserved or degrade the temporal and rate information. Because the original grant proposal was written for three years and we received funding for only 18 months, these experiments were not begun. During the beginning period of the grant, a few preliminary experiments were carried out to investigate whether nonlinearities in the spectral envelope of the cochlear microphonic occur in response to rippled noise (see Detailed Progress Report).

DETAILED PROGRESS REPORT

Rate responses of cochlear nucleus cells.

The information that the central nervous system has available to it about stimulus features of acoustic signals is present in the trains of action potentials in the auditory nerve. The encoding of the stimulus features in these spike trains can be based on the time intervals between individual spikes or can be based on the average discharge rate. The temporal and rate information present in the auditory nerve is then processed in the various subsystems of the cochlear nucleus. While temporal codes have been shown to provide robust representation of stimulus features over a wide range of sound pressure levels, it has been stated that there are no data that can unequivocally eliminate coding schemes based on average rate (Sachs and Young, 1979; Sachs et al, 1986; Winslow et al., 1987).

One of the difficulties in evaluating coding schemes based

on average discharge rate is the question of what constitutes a significant change in discharge rate when a stimulus feature changes. Figure 1 a & b show PST histograms obtained from a cochlear nucleus unit in response to 100 presentations of a 400 msec 1790 Hz BF tone burst at levels of 81 and 83 dB SPL. A casual comparison of these PST histograms might suggest that there is little if any increase in discharge rate for the 2 dB increment in sound pressure level. Empirical spike count distributions for these two conditions are shown in Figure 1 c & d. The mean spike counts produced in response to the 81 and 83 dB SPL tone bursts are 36.01 and 40.56 spikes, respectively.

In order to obtain a more objective measure of whether the 2 dB increment in level is detectable based on the average firing rate of the neuron, Receiver Operating Characteristic (ROC) curves were generated from the empirical spike count distributions by sweeping a criterion through the two distributions. For each criterion, the probability of a hit ($P(\text{hit})$) and the probability of a false alarm ($P(\text{false alarm})$) were calculated. The solid curve in Figure 1e shows the ROC function obtained from the two distributions in Figure 1 c & d. As a measure of detectability, the ROC curve was integrated to yield the area under the curve or $P(A)$. $P(A)$ is the probability that an ideal observer can detect the 2 dB increment based on the two spike count distributions in a two-alternative forced choice task. The value of $P(A)$ for the ROC curve shown in Figure 1e is 0.76; that is, an ideal observer would correctly detect the 2 dB increment in level 76% of the time based on the spike count distributions of the neuron. For comparison, the dotted line in Figure 1e shows the theoretical ROC function that would be obtained if the two distributions were identical. $P(A)$ for this theoretical curve is 0.5. The advantages of using $P(A)$ as a measure of sensitivity are it is easy to compute, it is a distribution-free measure, and it can be easily compared with psychophysical results.

Based on inter-spike interval histograms, units are characterized as irregular or regular. Regular units have coefficients of variation (CV) of their inter-spike intervals of less than 0.4, while irregular units have CVs greater than 0.5. Regular units are generally characterized by chopper discharge patterns; irregular units include primary-like (pri), primary-like with a notch (pri-n), phase-lockers, on-L and transient choppers (chop-t). Figures 2-6 show examples of the response characteristics of these unit types.

Figures 7-9 show scatter diagrams of $P(A)$ as a functions of the difference in the means of two spike count distributions for the various unit types in the cochlear nucleus. Regular units typically give larger values of $P(A)$ for a given mean difference than do primary-like and transient chopper units. Moreover, primary-like with a notch and on-L units also give larger $P(A)$ values than do primary-like and transient chopper units.

These data are consistent with the hypothesis that information in average rate is enhanced by certain subsystems in

the cochlear nucleus.

Cochlear microphonic response to rippled noise.

Recent experiments by Wit and Horst (1986) showed that at high stimulus levels, there is an enhancement or amplification of the peak-to-valley ratio of the spectral envelope of the cochlear microphonic in response to filtered pulse trains. This 'contrast enhancement' of the microphonic spectral envelope was attributed by these authors to the nonlinear properties of the cochlea. The spectral envelope of rippled noise has multiple peaks and valleys which vary along the frequency domain in a cosinusoidal fashion. A major difference between the spectra of rippled noises and the filtered pulse trains used by Wit and Horst is that the former have continuous spectra, while the latter have line spectra. Preliminary experiments were carried out to investigate the cochlear microphonic responses to rippled noise. In particular, we were interested in whether 'contrast enhancement' of the spectral envelope occurs for a continuous spectrum stimulus like rippled noise.

Adult mongolian gerbils were anesthetized with sodium pentobarbital, and the cochlear microphonic was recorded at the round window. Pseudorandom rippled noise was presented and the cochlear microphonic was digitized over the duration of the stimulus. A fast Fourier transform was carried out on the averaged microphonic waveform in order to obtain the spectrum.

Preliminary data suggest that 'contrast enhancement' of the cochlear microphonic spectral envelope does not occur for stimuli having continuous spectra. In none of the microphonic spectra obtained does the depth of the ripple appear to be enhanced or amplified. We obtained similar results when simulations of the cochlear microphonic were carried out using a nonlinear analog model (Engebretson-Eldredge, 1968).

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Abstracts

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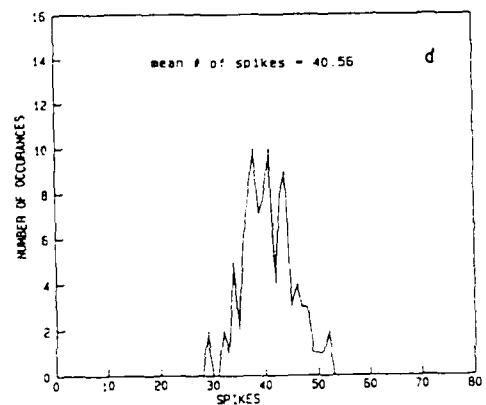
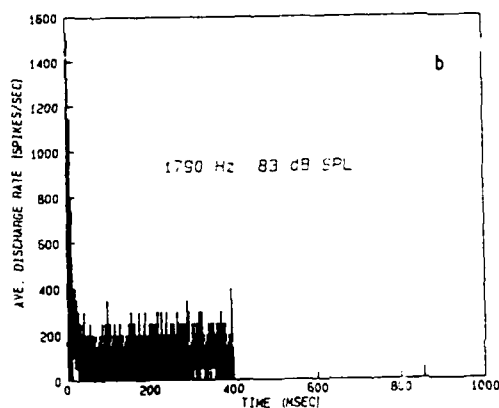
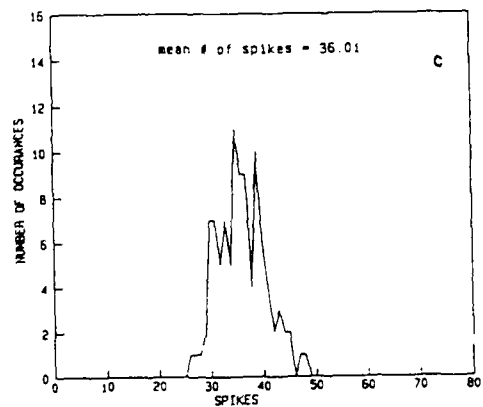
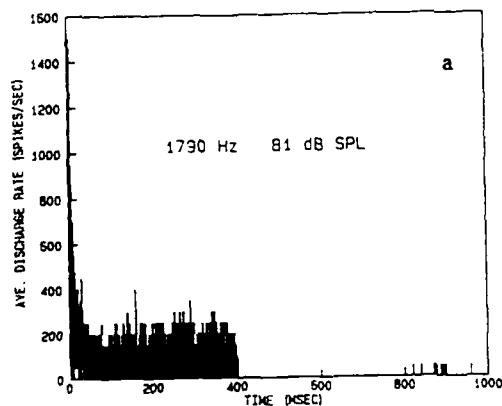
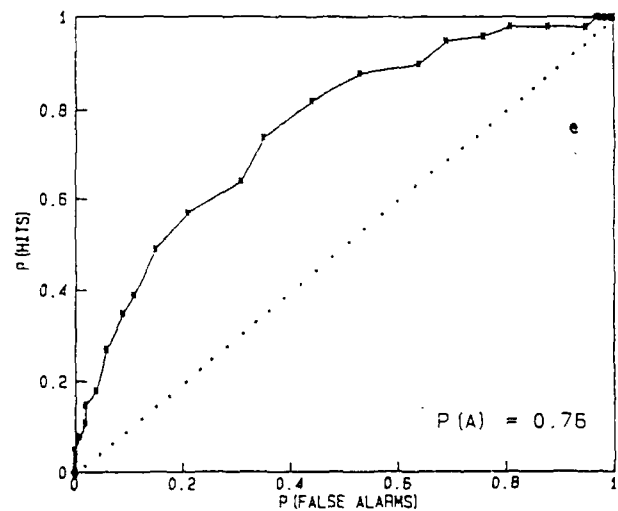


Fig. 1. a,b) PST histograms obtained from 100 presentations of a 400 msec BF tone burst for a cochlear nucleus unit for the SPLs indicated. Based on the onset portion of the PST histogram, this unit could be classified as a transient chopper.

c,d) Empirical spike count distributions for the PST histograms in Fig. 1 a & b.

e) ROC function generated from the distributions in Fig. 1 c & d (SOLID LINE). $P(A) = 0.76$. Theoretical ROC function (dotted line) expected if the two distributions were identical.



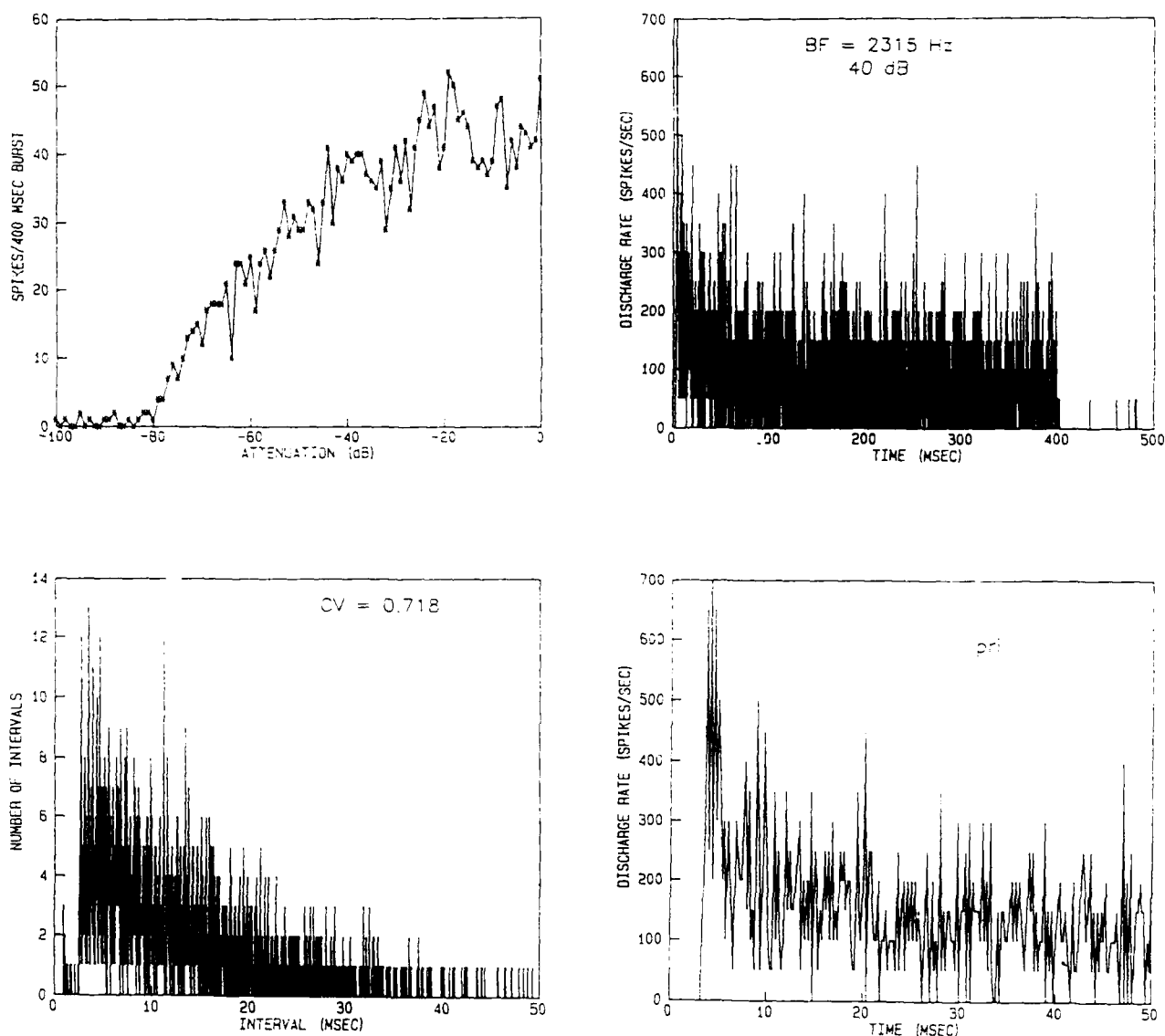


Figure 2. Response characteristics for a primary-like unit. In this and Figs. 3-6, the rate vs. sound level function at best frequency (BF) is shown in the upper left panel. The upper right panel shows the post-stimulus time (PST) histogram for a 400 msec BF tone at the indicated attenuation. The lower left panel shows the interspike interval histogram for intervals between 20-400 msec of the response in the PST histogram in the upper right panel. The lower right panel shows the first 50 msec of the PST histogram in the upper right panel and shows the details of the onset portion of the discharge pattern.

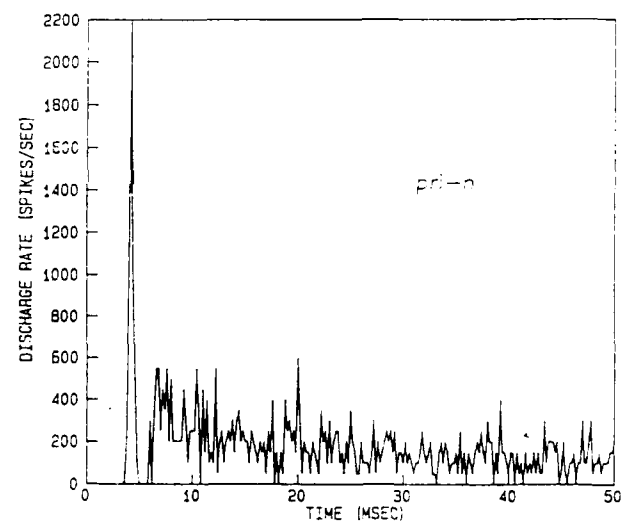
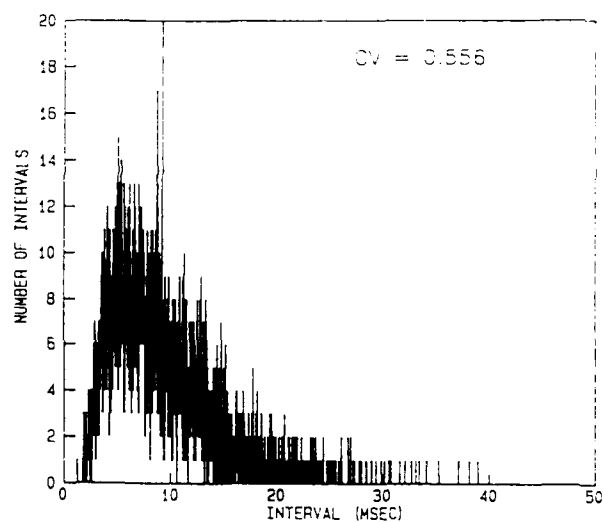
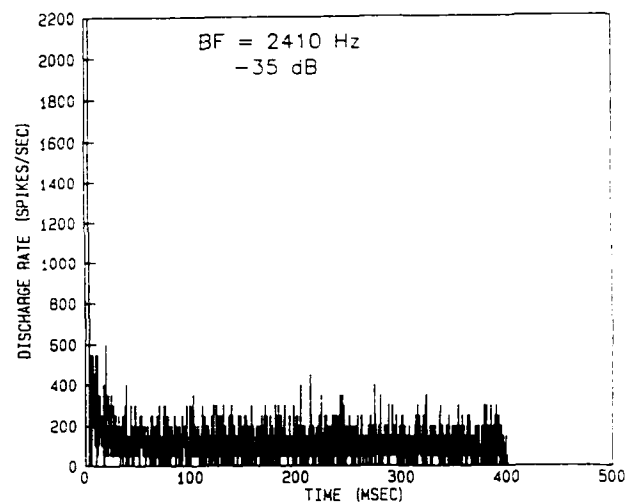
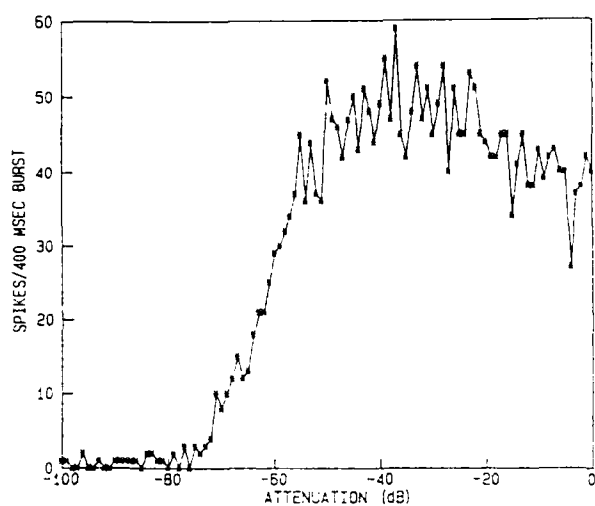


Figure 3. Response characteristics of a primary-like with a notch unit.

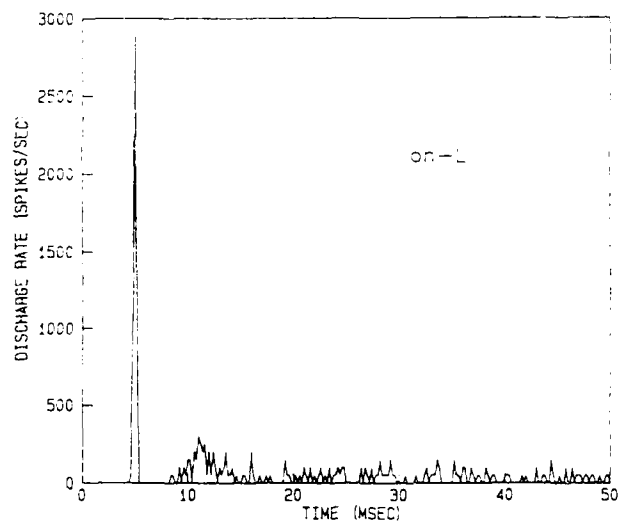
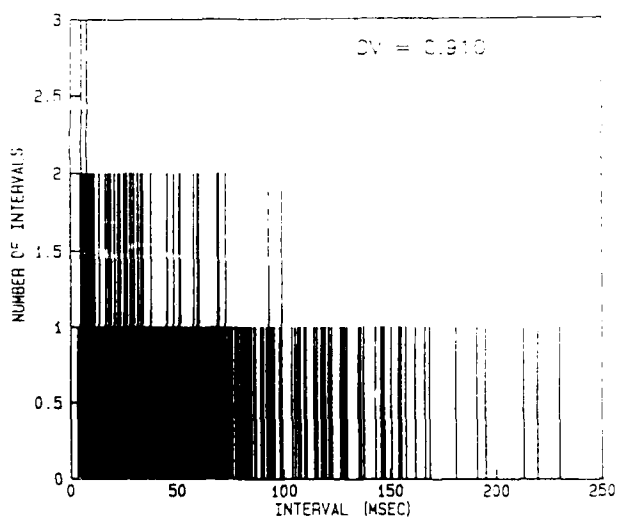
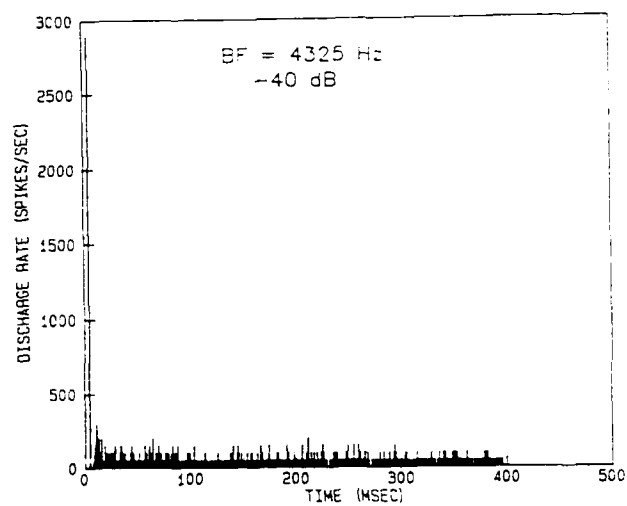
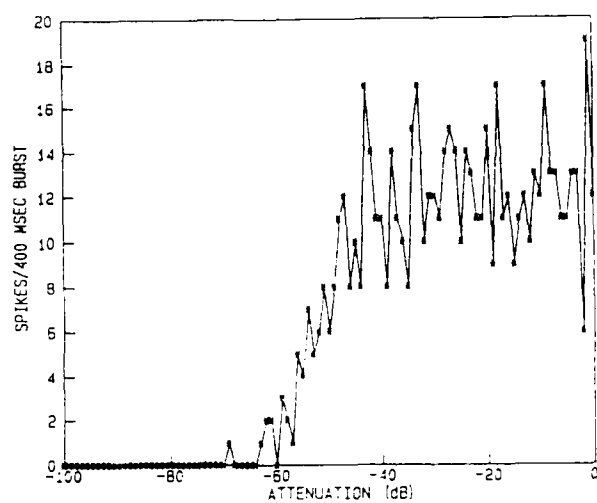


Figure 4. Response characteristics of an on-L unit.

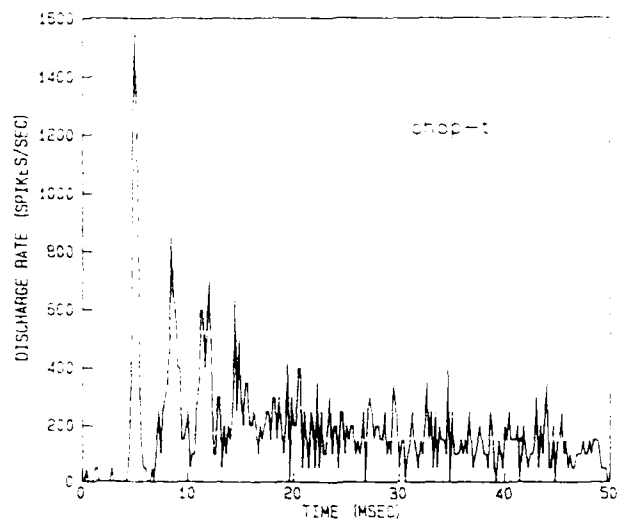
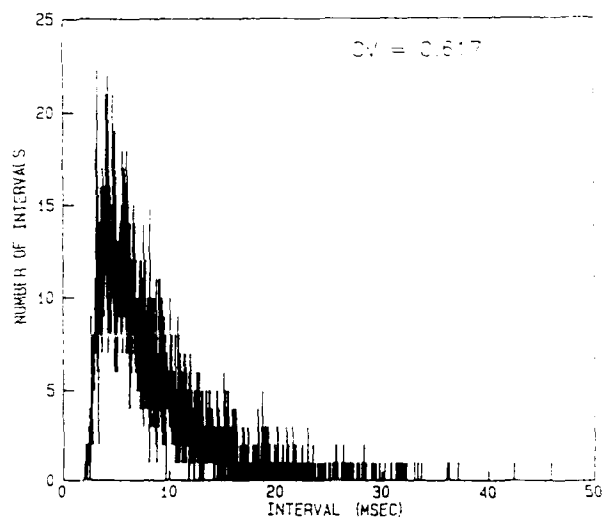
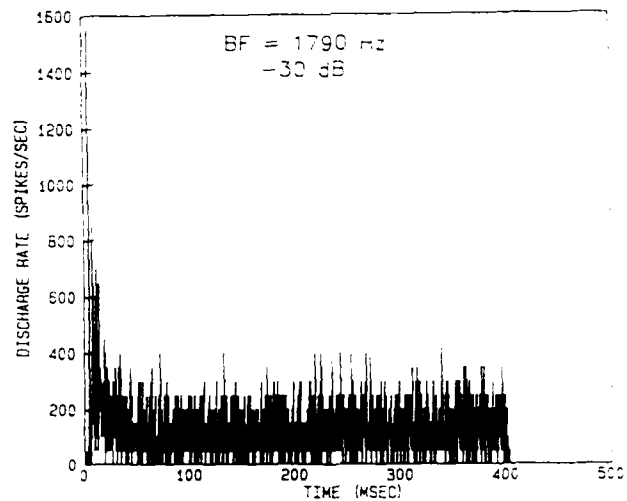
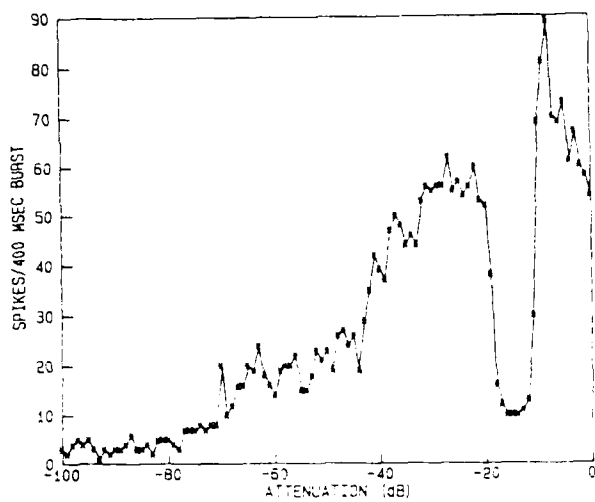


Figure 5. Response characteristics of a transient chopper unit.

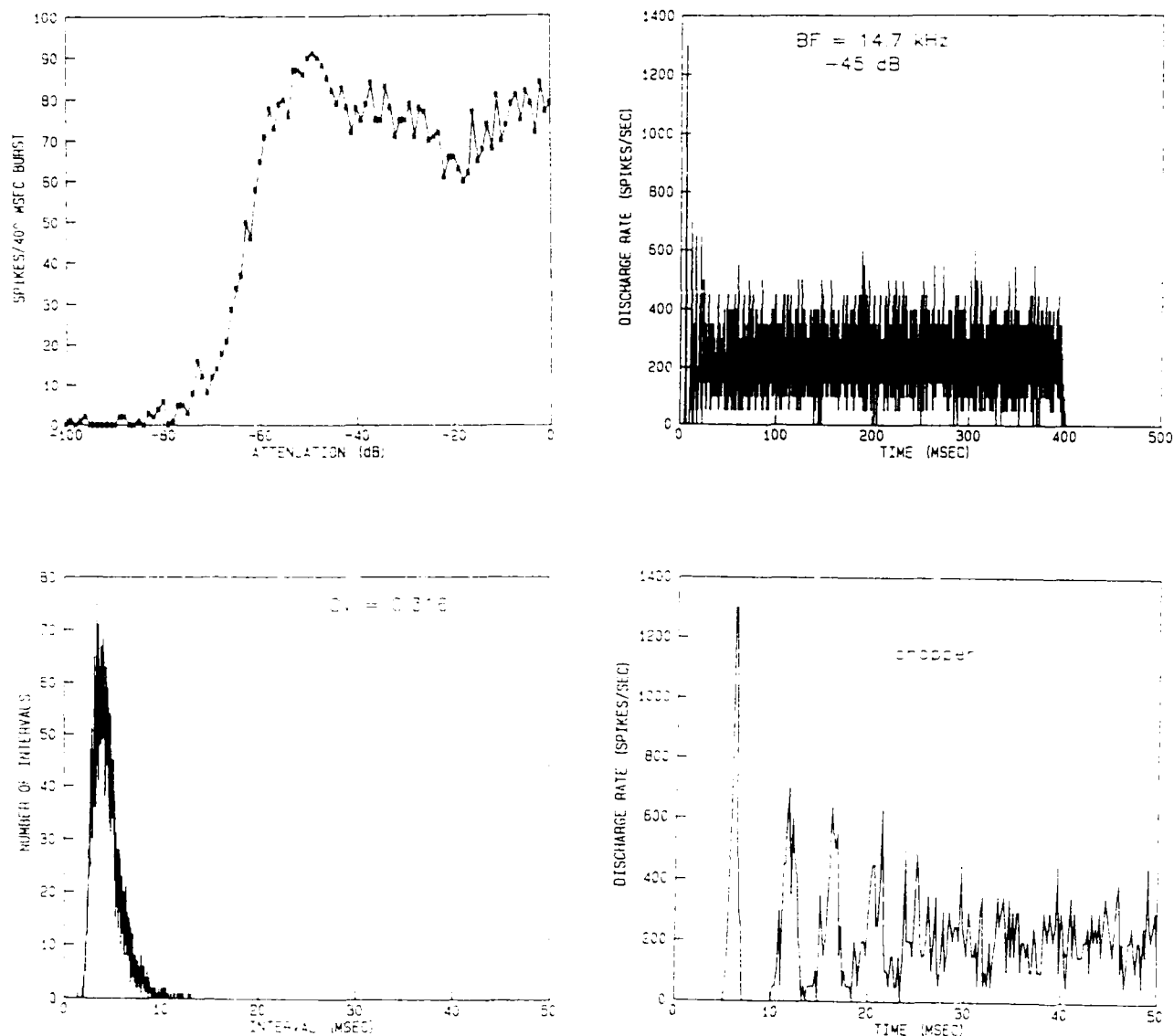


Figure 6. Response characteristics of a chopper unit. Note that while the PST histogram in the lower left panel is similar to that of the transient chopper shown in Fig. 5, the chopper has a lower CV in its interspike intervals (lower left panel) than does the transient chopper. This indicates that the chopper has a more regular discharge than the transient chopper which is irregular and similar to primary-like units.

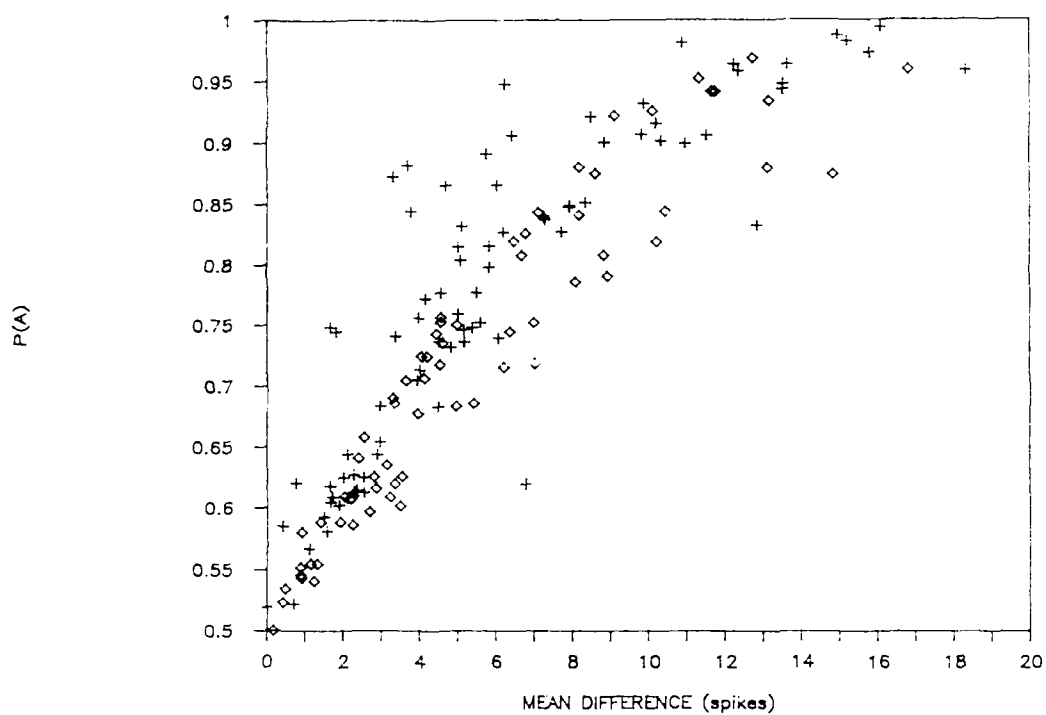


Figure 7. Scatter diagrams showing values of $P(A)$ vs. the difference in the means of two spike count distributions for primary-like (+) and transient chopper (◇) units. For a given mean difference, primary-like and transient chopper units give similar $P(A)$ values.

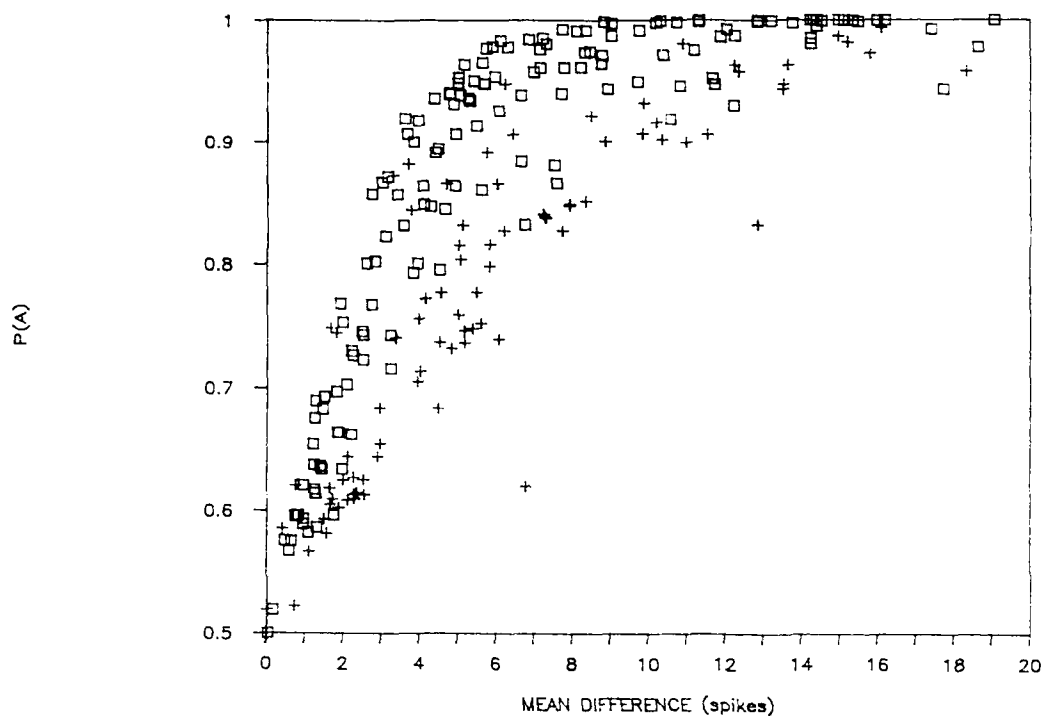


Figure 8. Scatter diagrams of $P(A)$ vs. the mean difference for primary-like (+) and regular (□) units. For a given mean difference, regular units typically give larger $P(A)$ values than do primary-like units.

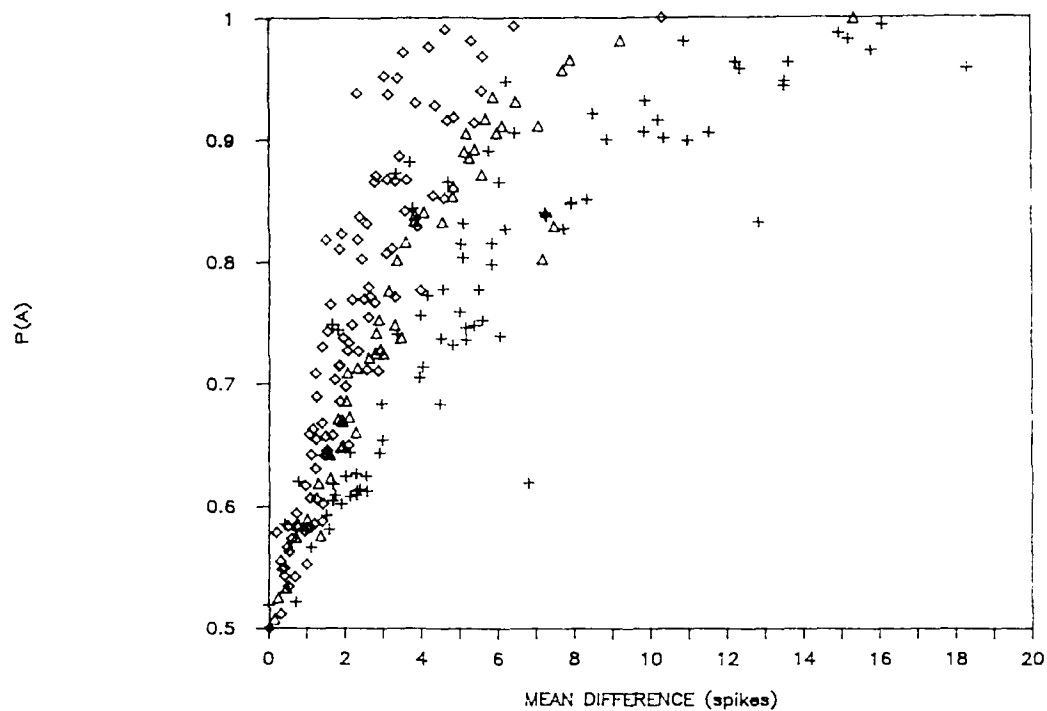


Figure 9. Scatter diagrams of $P(A)$ vs. the mean difference for primary-like (+), primary-like with a notch (Δ), and on-L (\diamond) units. For a given mean difference, on-L and primary-like with a notch units give larger $P(A)$ values than do primary-like units.